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Mercury: A High Repetition Rate Laser for High Energy Density Physics

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June 12, 2006

29th European Conference on Laser Interaction with Matter
Madrid, Spain
June 11, 2006 through June 16, 2006

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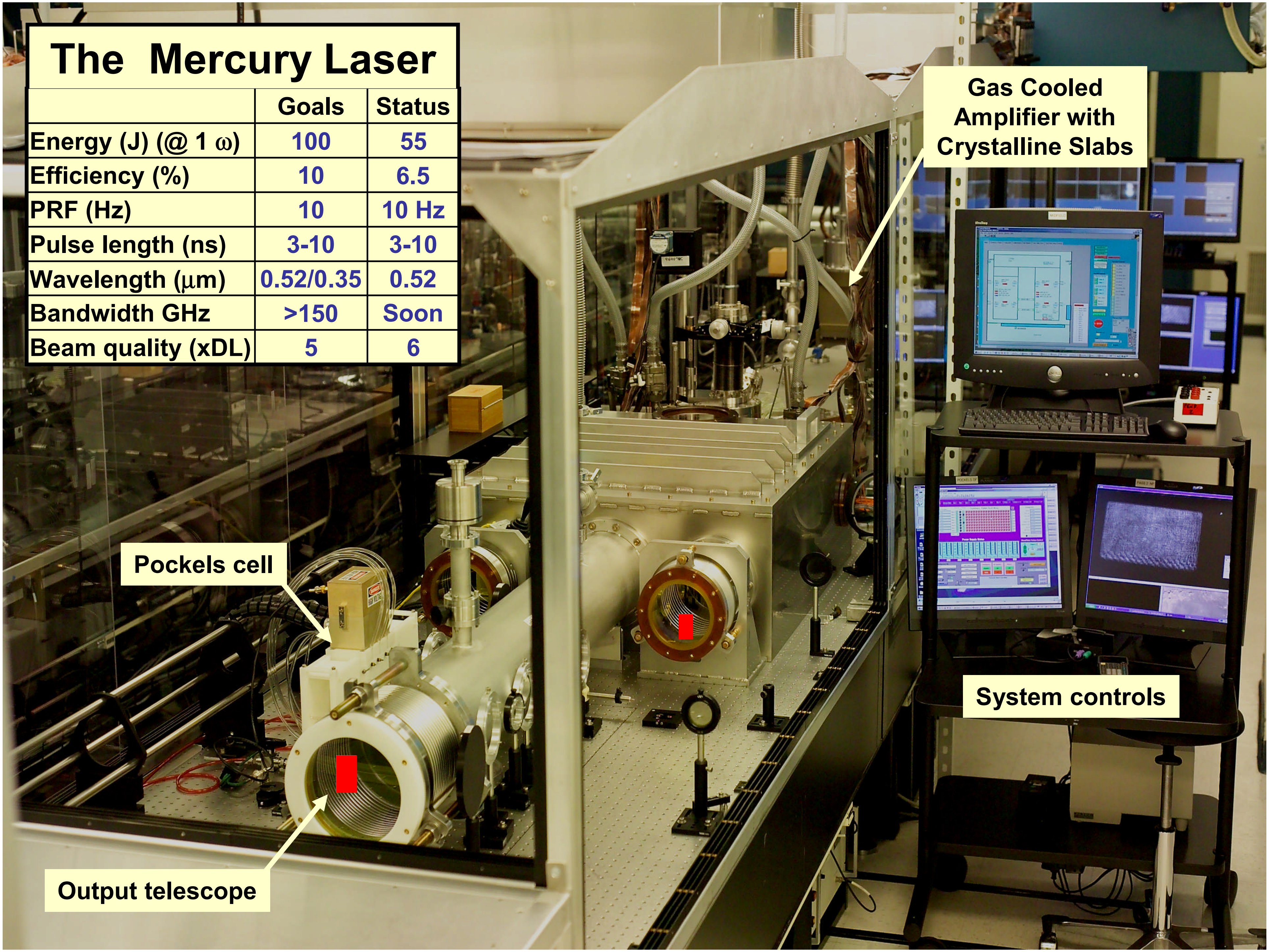
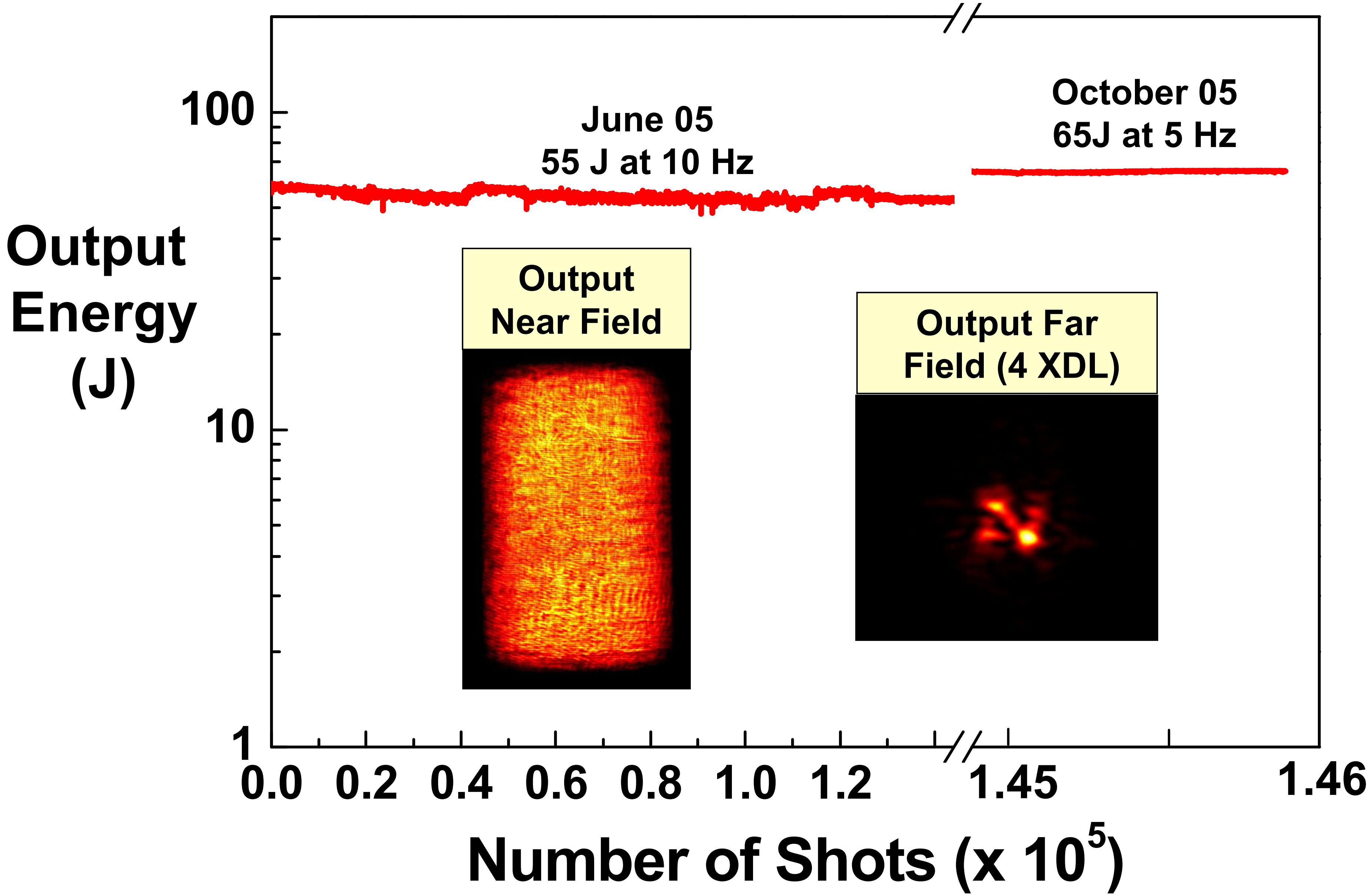
RJB/VG

The Mercury Laser

	Goals	Status
Energy (J) (@ 1 ω)	100	55
Efficiency (%)	10	6.5
PRF (Hz)	10	10 Hz
Pulse length (ns)	3-10	3-10
Wavelength (μm)	0.52/0.35	0.52
Bandwidth GHz	>150	Soon
Beam quality (xDL)	5	6

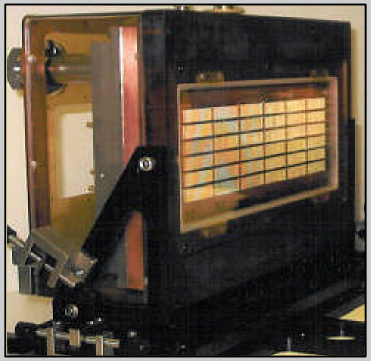


Mercury demonstrated 550 W for > 10^5 shots

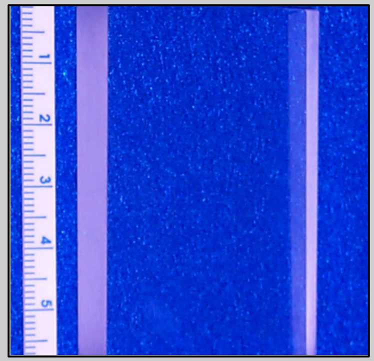


Mercury uses advanced state-of-the-art technology

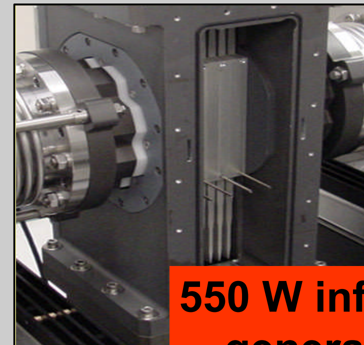
Diode pump arrays
- Commercialization
- 70% Efficiency



Solid-state amplifier
- Improved Yb:SFAP quality
- 12 cm diameter growth

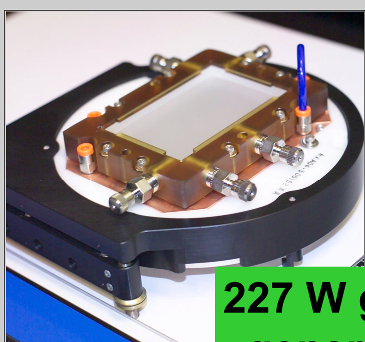


Helium gas cooling
- Low thermal wavefront
- 4 hours operation @ 10 Hz



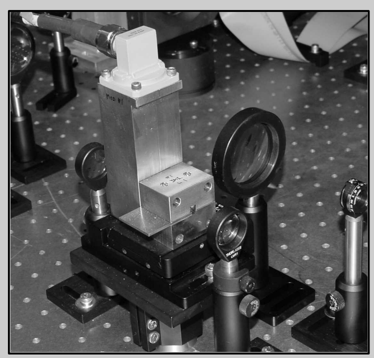
550 W infrared generated

Frequency Converter
- 5.5 x 8.5 cm^2 YCOB slabs
- Scalable cooling design



227 W green generated

Broadband Front End
- Fiber based design
- 340 mJ demonstrated



Adaptive Optic
- High resolution sensor
- 41 act. bi-Morph mirror

Mercury will reach performance goals in 2006-2007. User facility activation also expected in 2007

Components	Goal		Present	End FY06
Amplifier slabs (4x6 cm)	14	√	14	28
Diode tiles (120 W/bar)	288	√	360	360
Amplifiers	2	√	2	2
- Cooling uniformity (rms)	<1%	√	0.12%	0.12%
2ω Conversion crystals	2	√	3 YCOB/4 KDP	Better YCOB
3ω Conversion crystals	4		2 KDP	Assess perf.
Wavefront control	1 DM	√	Commissioned	Online
Laser Performance				
Energy (J)	100		55 (65 J)	>60
Rep-rate (Hz)	10	√	10	10
Efficiency (%)	10		4.5	>6
Diode reliability (shots)	10^8	√	10^9	10^9
Beam quality (xDL)	5		6 @ 55J (80%)	<5
Pulse-shaping (ns)	3-10		15	3-15
Bandwidth (GHz @ 1ω)	>150		Offline	Qualified
Conversion	2ω/3ω		2ω	2ω/3ω

√ Completed

A HED target shooting experimental facility using Mercury is highly synergistic with IFE goals

- Target experiment requirements are similar
- HED physics for IFE
- X-ray source for diagnostic calibrations
- Laser component lifetime

A high repetition rate User Facility has numerous advantages

- Accurately measure statistical variability of phenomena
- Signal to Noise (S/N) enhancement by signal averaging
- Measure entire parametric variation in a single run, e.g.,
  - Drive energy
  - Pulse – diagnostic delay
  - Pulse duration
  - Gas pressure (jet)
  - Target composition, or gas mixture (e.g., He-H ratio)
  - Target aspect ratio

Repetitively pulsed systems are the way for the future

Mercury capability will increase in phases

	Phase 1 - 2006	Phase 2 – 2006-2007	Phase 3 – 2007-09
Define in detail	Mercury in current state	Mercury + adaptive optics and FE w/bandwidth	Mercury short pulse option + new room
Energy and rms	50 J +/- 5% (70-100 J next quarter)	100 J +/- 5%	<100 J +/- 5%
Pulse length and shape	15 ns +/- 10% ampl fluctuations	3-15 ns +/- 10% ampl fluctuations	30 fs - 10 ps
Energy in bucket (100% diameter and 80% diameter)	Est. 4.2 x 7.2 cm beam & 1 meter lens 96% energy in 0.525 mm dia. 80% energy in 0.325 mm dia. 20% energy in 0.05 mm dia	Goal: 4.2x7.2 cm beam & 1 meter lens 80% energy in 0.25 mm dia. 40% energy in .05 mm dia.	Goal: 4.2x7.2 cm beam & 1 meter lens 80% energy in 0.05 mm dia.
Wavelength	1.047 um	1.047 um	TBD
Bandwidth	20 MHz	250 GHz	250 GHz to >33 THz
Diagnostics	Near field / Far field / Wavefront / Energy / Temporal	Near field / Far field / Wavefront / Energy / Temporal	Near field / Far field / Wavefront / Energy / Temporal / autocorr
Shot rate (Hz)	Single, 0.1,1,3,5,10, burst	Single, 0.1,1,3,5,10, burst	Single, 0.1,1,3,5,10, burst
Frequency conversion	2ω	$2\omega/3\omega$	$2\omega/3\omega$ (long pulse), 0.8,1.0,1.6,2.0 micron short pulse
Pump/probe option	Yes - 2 long pulses	Yes – 2 long pulses	Yes
Target chamber	In lab small chamber, CY2006	small chamber then new room	New room + Short pulse system

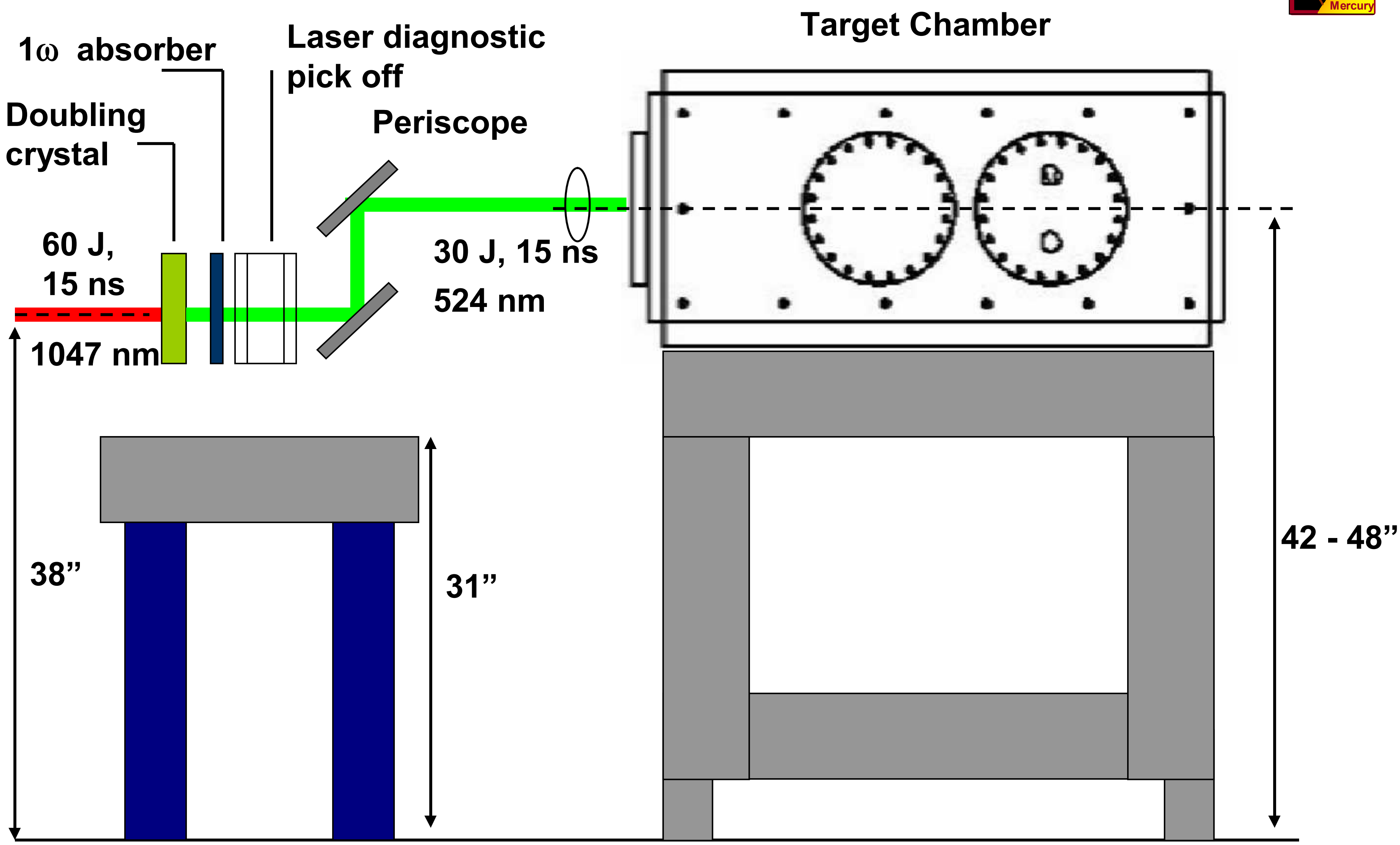
Separate experiments by pulse requirements I: IFE optics testing and Phase I & II long pulse

• Laser damage (IFE final optics)	Latkowski	IFE
• Longevity of other IFE laser components	Ebbers/Bayramian	IFE
• X-ray calibration (sensitivity and/or timing)	Holder/Young(s)/Izumi/+	X-ray
• Point projection imaging	Landen	X-ray
• Extreme chemistry w/CARS	Collins/Page	Shock
• X-ray diffraction of shocked materials	Lorenzana/Kalantar	Shock
• SBS & SRS backscatter from gas/plasma	Froula/Glenzer	LPI
• Thomson scattering (intrinsic and/or collective)	Glenzer	LPI
• Laser-Plasma Interactions (LPI)	Young/ Patel	LPI
• LPI – two plasmon decay (LDRD proposal)	Kirkwood/Payne	LPI
• 1ω pre-pulse effects measurements for NIF	Kalantar	NIF
• Debris and shrapnel effects	Kalantar/Koniges	NIF

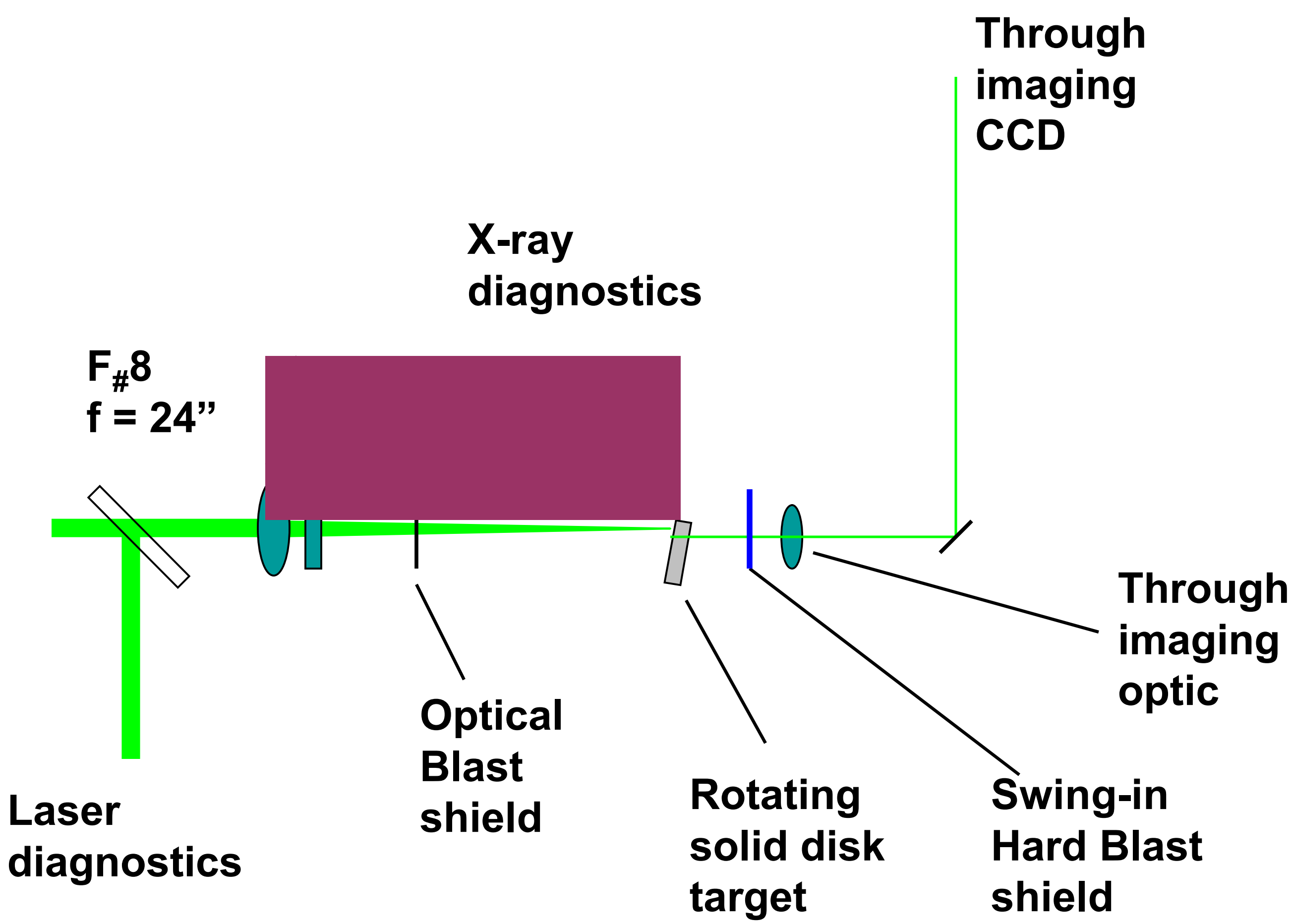
Separate experiments by pulse requirements II: Short pulse Mercury, Phase III

• Filamentation and remote sensing	Stuart	Visible light
• Proton radiography	MacKinnon	MeV protons
• Proton induced isochoric heating	Patel/Eckart/Osterheld	MeV protons
• Fast ignitor, hot electron transport	MacKinnon/Key	MeV electrons
• Hard x-ray backlighter development	Park/Koch	K-a X-rays
• X-ray probe of transient lattice structure/melting	Lorenzana	K-a X-rays
• GRIP X-ray laser and applications	Dunn/Nelson/Rocca …	X-ray Laser
• Neutron generation for NIF sensor calibration	Young	Neutrons
• Neutron generation for medical isotopes	Ditmire	Neutrons
• High flux neutron source for materials research	Perkins	Neutrons
• HEDP plasma spectroscopy development (LDRD)	Shepherd/Dunn	X-rays

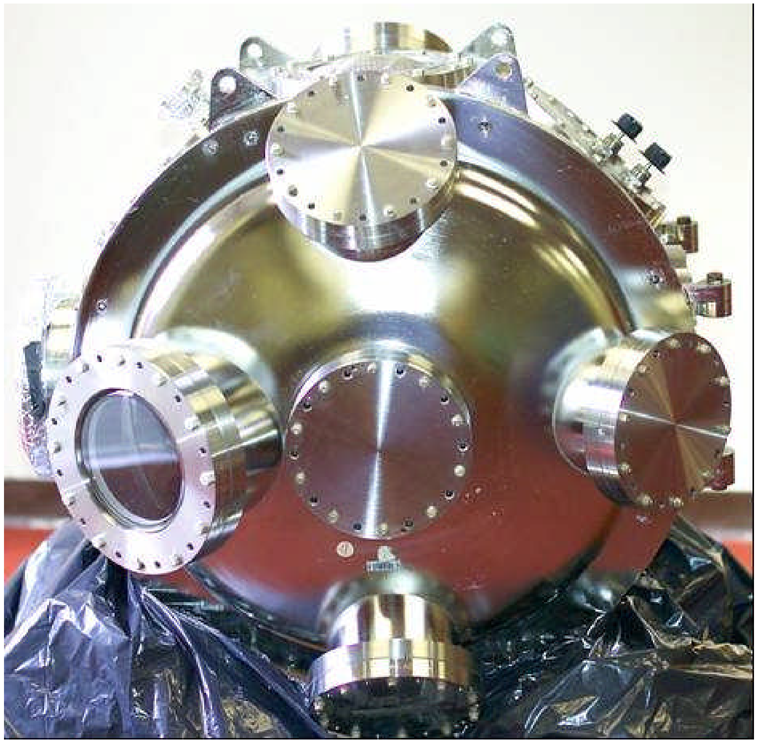
Our Phase I User Facility Plan will use1047 nm or frequency-doubled 524 nm beam



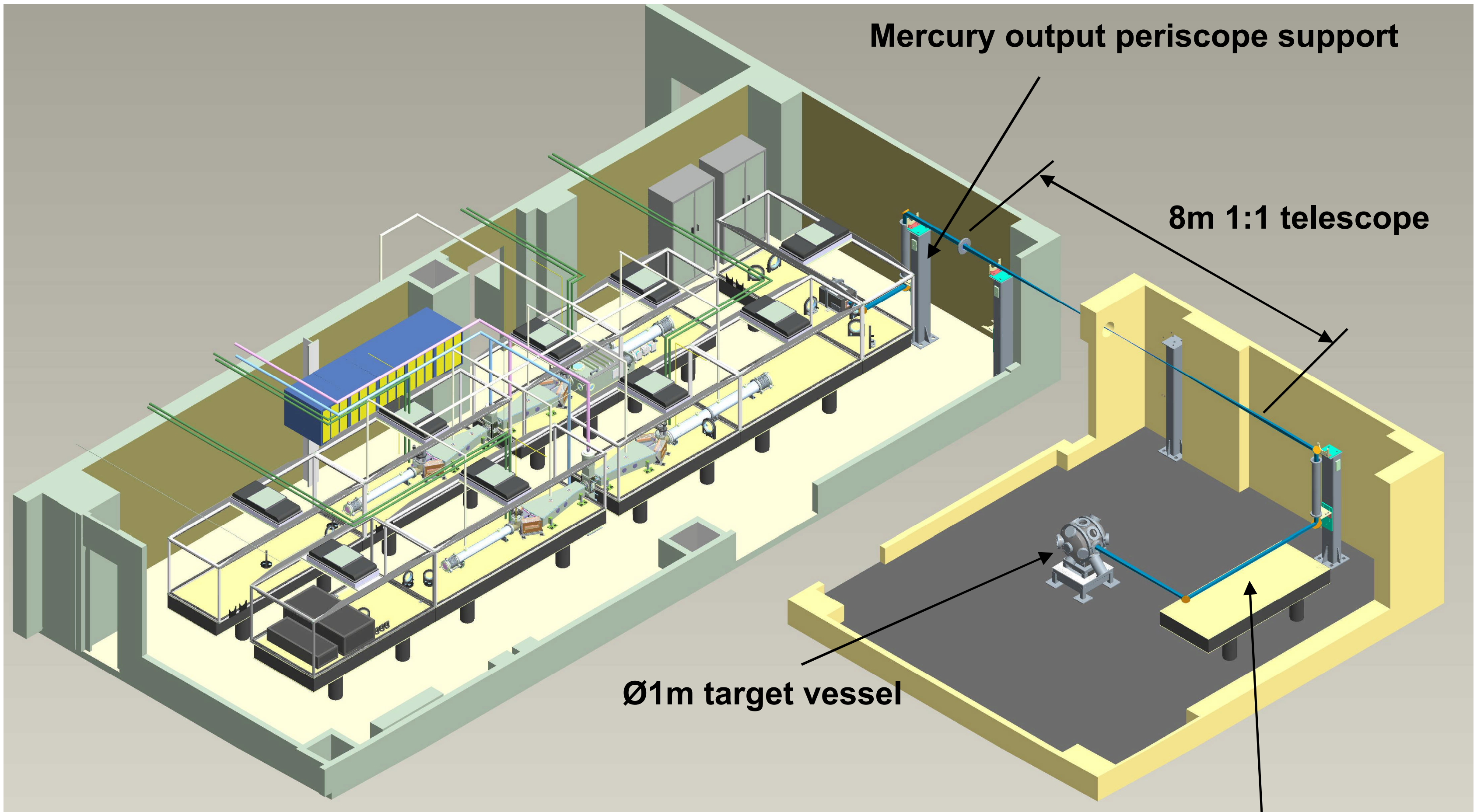
Solid target inclined at an angle to divert debris and plasma blow-off from input optics



Phase II & III: Janus target chamber has been acquired for initial experiments on Mercury



We have identified a laboratory for Phase II activities



Two white papers on target physics applications of Mercury have been written

LAWRENCE LIVERMORE NATIONAL LABORATORY

Mercury High Average Power X-ray Laser

James Dunn

28 October 2005

Internal LLNL Report

Extreme Chemistry Using Mercury—short version

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7 Sept 05

I. Introduction
Stars and giant planets contain matter that exists under ultra-high-pressure conditions, compressed several-fold with respect to its specific volume at the Earth's surface. At such high pressures (millions of atmospheres,) as found at the core of the giant planets (Figure 1,) various phase changes will have occurred. Normally-insulating materials could even exist as metals. In this "extreme chemistry" regime, our 1-atm (1 bar) intuition no longer applies. Starting from a "particle-in-a-box" perspective, we realize that the "boxes" have become much smaller, the energy levels have shifted, and the electronic orbitals have become distorted. Orbital overlap, hybridization, and chemical bonding are radically different at high pressure, and although theoretical calculations have been done for many systems, stringent experimental tests are quite rare. In fact no experiments have ever probed the chemistry or molecular bonding that might exist under such conditions. So, we seek a means to do "extreme chemistry" experiments (at ultrahigh pressure) on Mercury, a laser system that provides the necessary and unique combination of high-energy pulses and high repetition rate enabling the signal averaging required to extract the detailed chemical nature of highly-compressed planetary fluids.

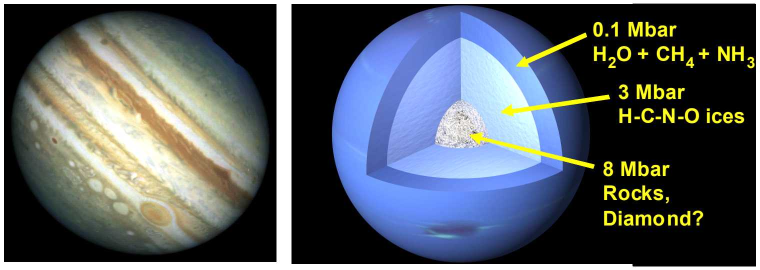
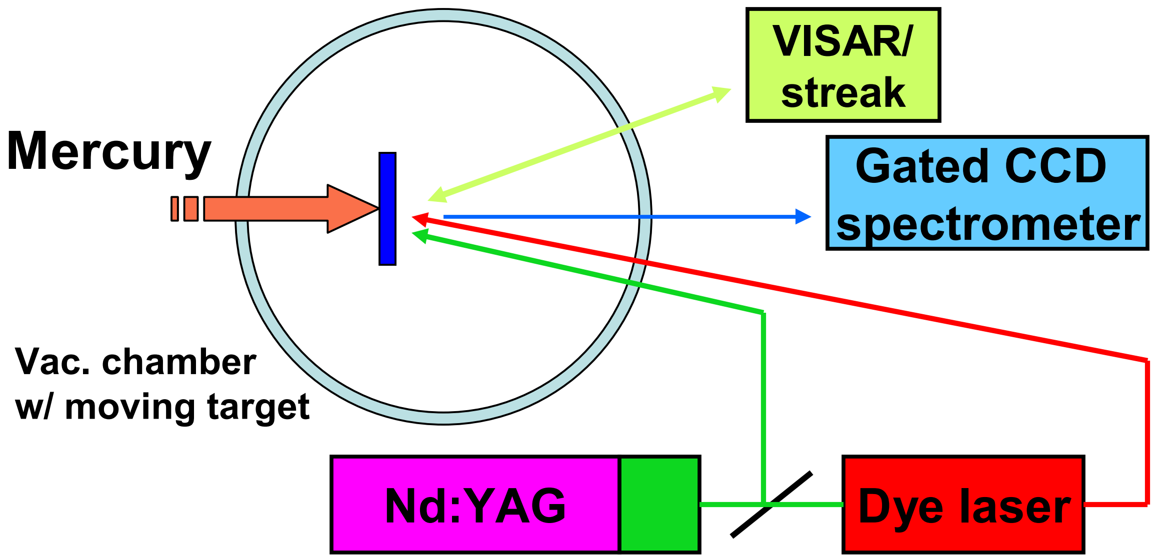
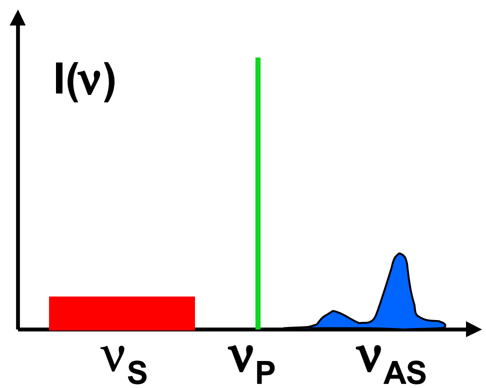


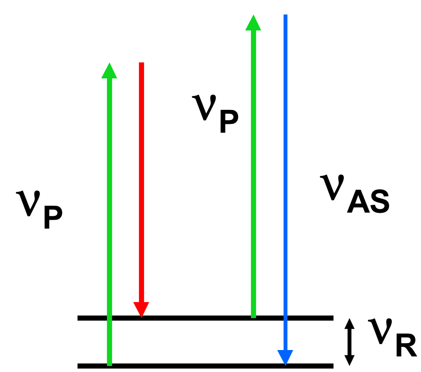
Fig 1. Matter in planets, stars, etc. exists at ultra-high pressures (over 1 million bar.) In general, even when the chemical compositions are known, the phases are not well-established. Jupiter and Neptune are primary examples. Closer to home, details of Earth's core-mantle boundary are not well-understood.

II. Laser-driven shocks
While experiments have begun to explore the pressure, density, and temperature of states expected to occur inside these giant planets, there exist no experiments looking at the high-pressure chemistry. To get a glimpse at the chemistry governing the interiors of stars, planets, and weapons, we will create samples at high pressure and then inspect them spectroscopically. The only way to create giant planetary core states is with

CARS probes vibrational spectrum of shocked matter; VISAR calibrates shock pressure (speed)



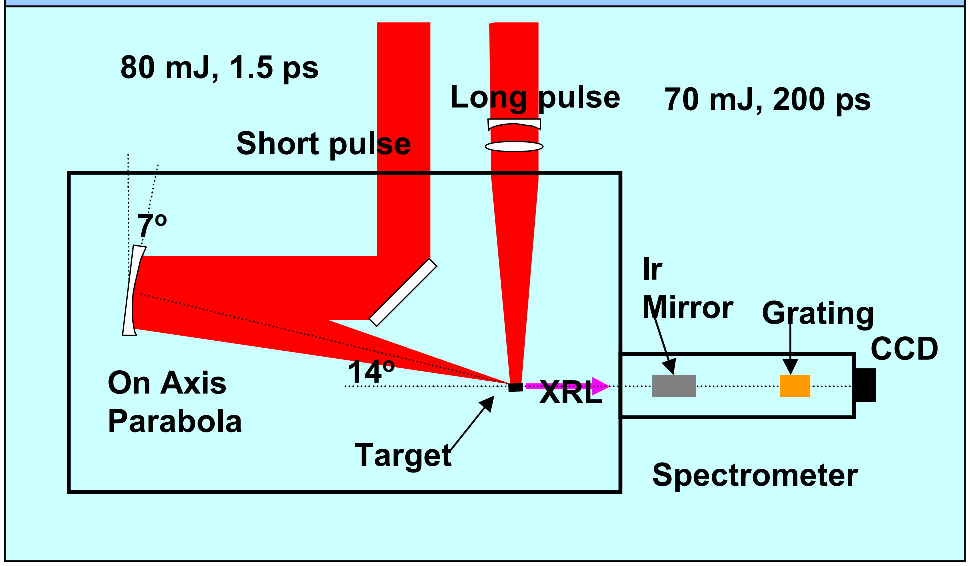


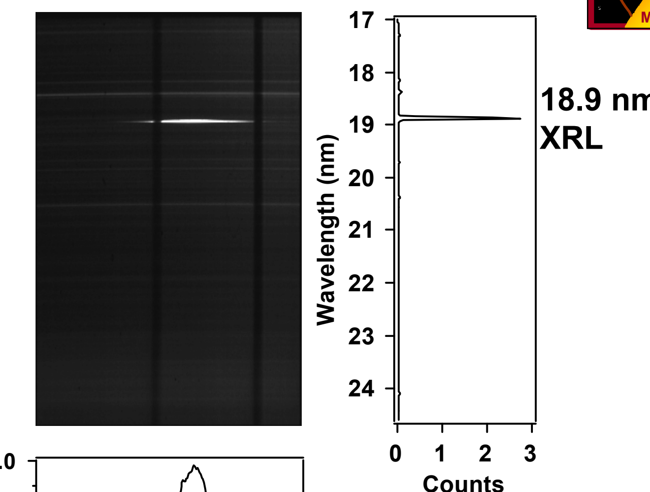


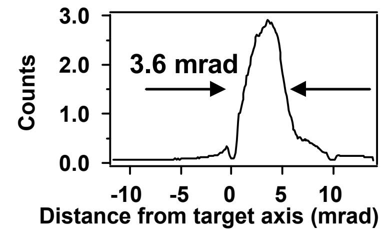
Experiment proposed by
Rip Collins and Ralph Page

Grazing Incidence Pumped (GRIP) x-ray laser produced by absorbing pump energy efficiently in gain region: 10 Hz XRL (by Jim Dunn)

Experimental Setup for 10 Hz GRIP X-ray Laser







Laser Pump:
150 mJ/pulse
at 10 Hz

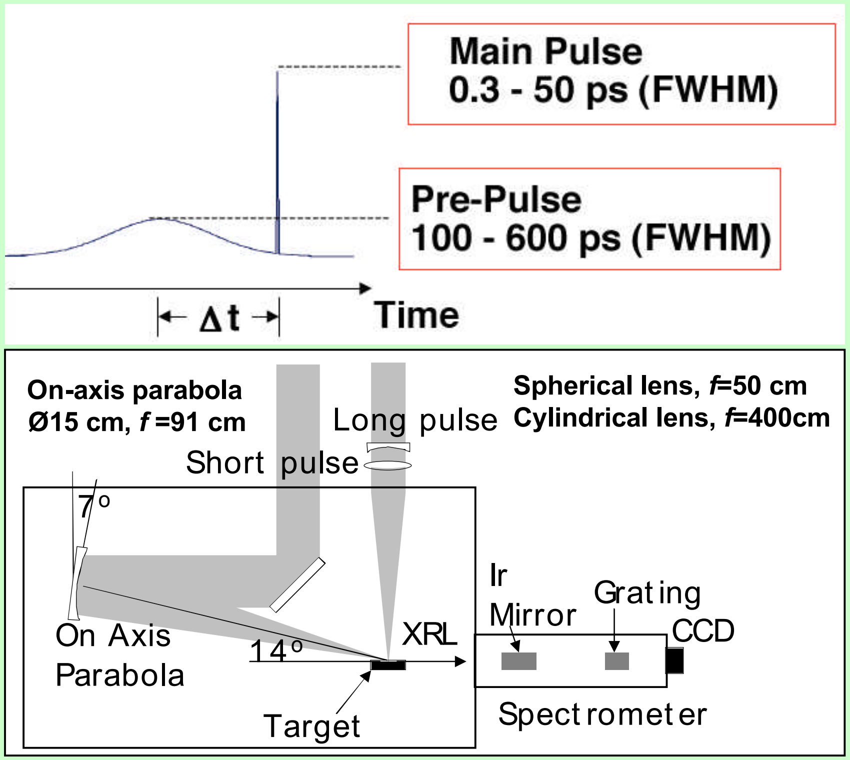
- Short pulse propagates in plasma up to a specific electron density
- Short pulse is then refracted back into gain region
- Short pulse angle given by $\theta = \sqrt{n_{e0}/n_{ec}}$ where n_{e0}= density at turning point
- Traveling wave pump inherent and no restriction on target length
- Absorption efficiency in gain region increases to 50% for GRIP

In collaboration with Slava Shlyaptsev, UC Davis

R. Keenan, J. Dunn, P.K. Patel, D.F. Price, R.F. Smith, and V.N. Shlyaptsev, "High Repetition Rate Grazing Incidence Pumped X-ray Laser Operating at 18.9 nm", Phys. Rev. Lett., 94, 103901-1 (2005).

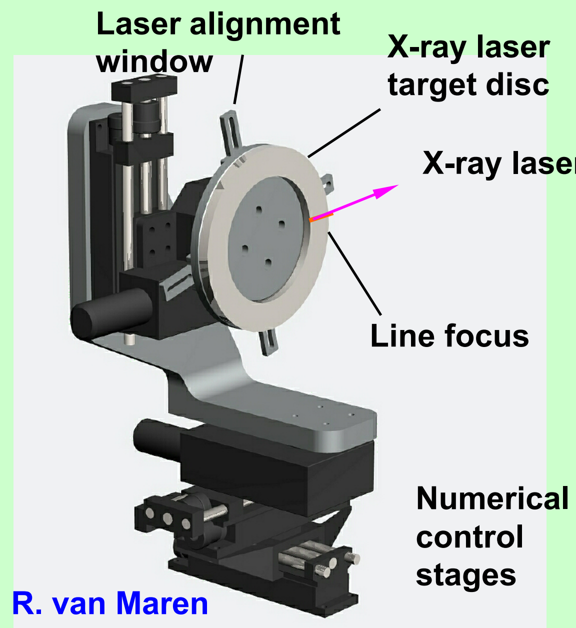
High repetition rate target manipulator allows high average brightness x-ray laser

Experimental Setup for X-ray Laser



- Two laser pulses required
- Grazing incidence short pulse beam on target
- Traveling wave achieved at close to ~c

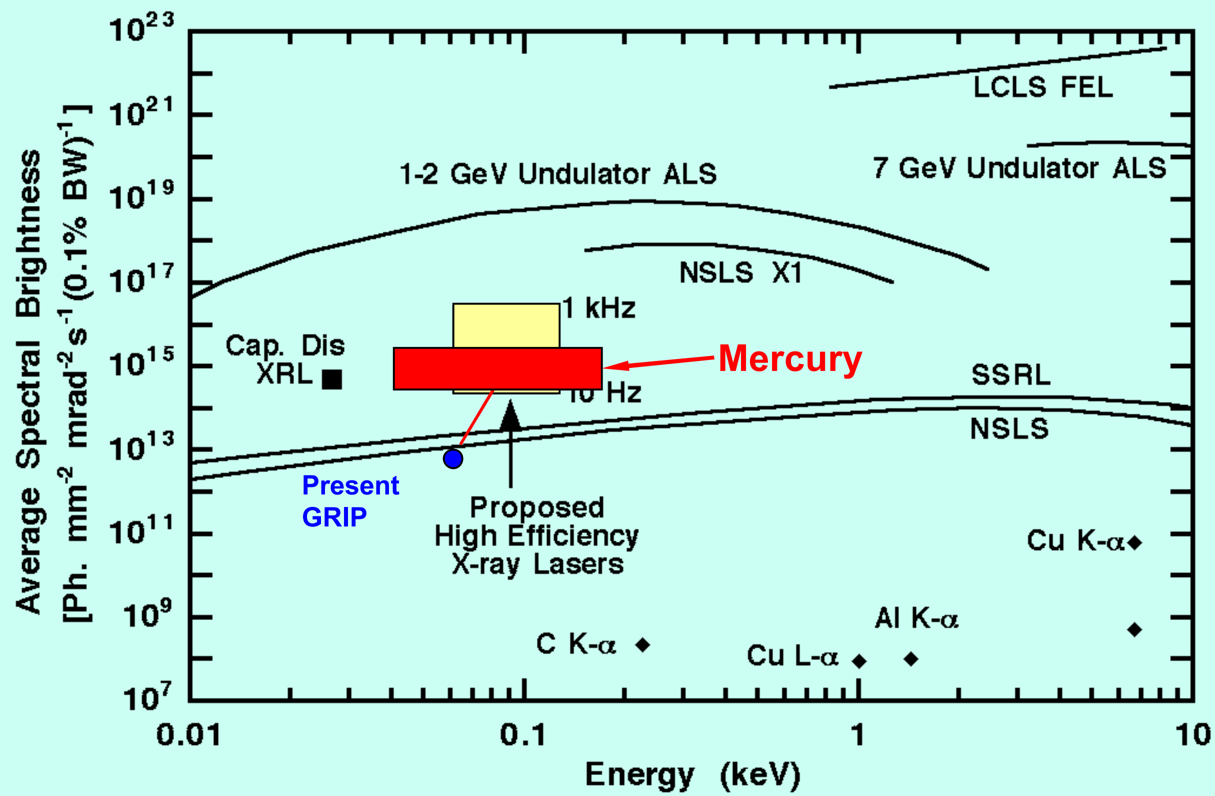
Target Design



- 40,000 shots/rotation in eroding target concept
- > 1 hour/rotation at 10 Hz rate
- Many rotations on 1 target disc

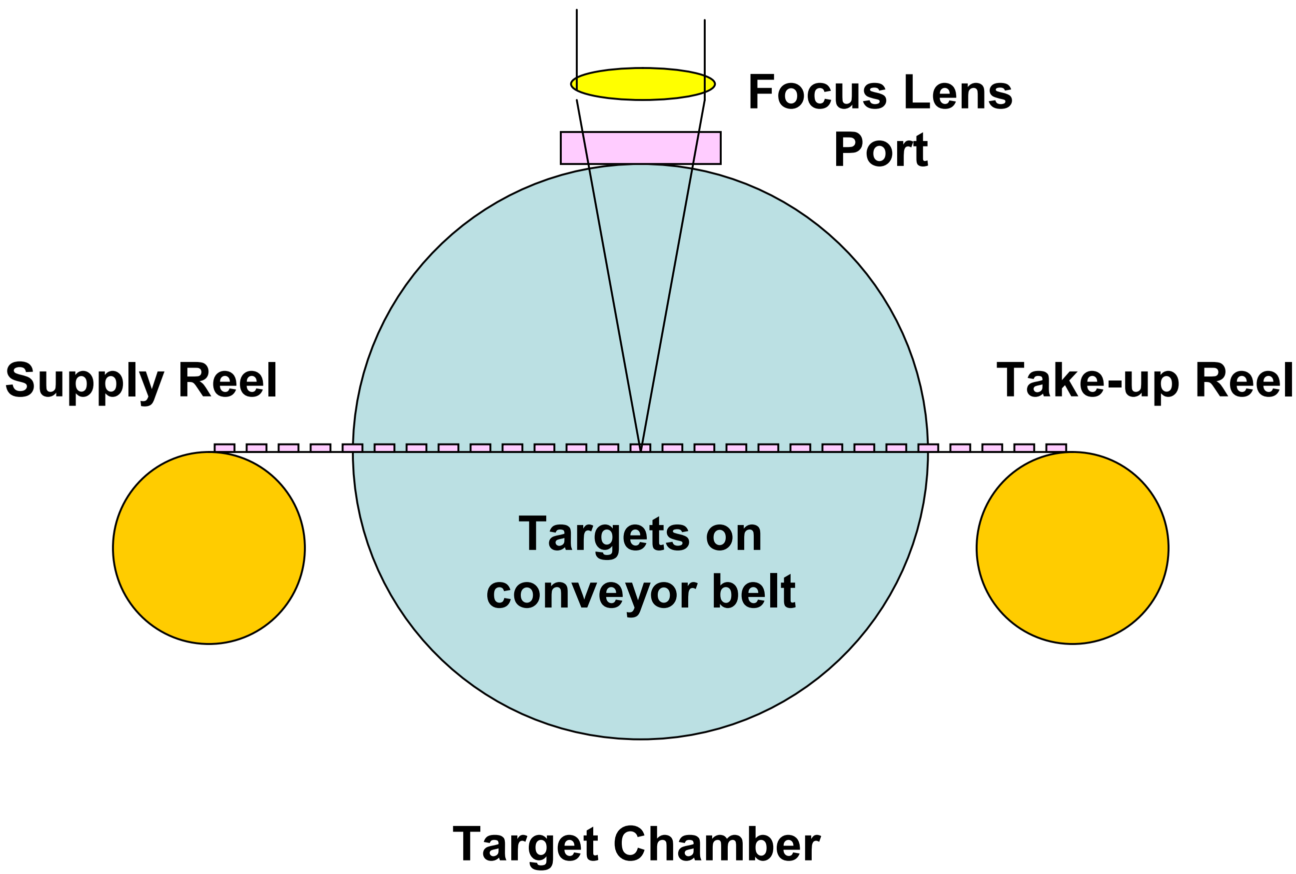
High average spectral brightness soft x-ray (60 to 200 eV) sources can be achieved on Mercury

Average Spectral Brightness vs E for Present and Future X-ray Sources



- Present GRIP 18.9 nm (66 eV) XRL pumped by 0.15 J, 10 Hz Callisto drive
- Projected GRIP 13.9 nm (89 eV) XRL pumped by 1 J, 30 Hz laser drive

New concepts are being developed for rapid target insertion and manipulation



Several complex target shots per second are possible with such a system

Summary

- Mercury User facility is highly synergistic with IFE goals
- We seek missions within NNSA that will result in new, unique capabilities, based on high rep rate.
- Several potential applications that have been proposed.
  - Short pulse applications appear most interesting
  - Short pulse laser architecture based on Ti:Sapphire likely due to long pulse duration of Mercury in near term
- Target manipulation and target debris are major issues to be addressed.
- Preliminary layout of target facility has been developed
- Draft schedule:
  - Phase I 2006, Mercury laboratory
  - Phase II 2007, new laboratory and target chamber
  - Phase III 2007- 2009, short pulse added